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International Hydrologic Science Programs and Global Water Issues

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1. INTRODUCTION

This chapter provides an overview of the purpose and role of international science programs that contribute to the resolution of water resource issues. Some of these issues are inherently global or at least multinational in nature, whereas others are of regional or local scale, but nevertheless are of global concern or have long-term future relevance and implications. The orientation for international hydrology and water resource programs may be toward either social or scientific goals, but all require participation by hydrological scientists to ensure the central issues are successfully addressed. This chapter considers the factors that are causing the hydrologic sciences to shift their focus from studies at the basin scale to studies at continental and global scales to more effectively address these larger scale issues. It also examines international mechanisms for conducting and applying science to water resource issues. Appendix A provides a listing of the numerous international programs referred to in this chapter that address some aspect of water resources. The coordination of science within an international policy framework can be challenging because it relies on trust and the development and pursuit of a shared vision. Even though the theoretical approaches are primarily apolitical, and the coordination frameworks are provided by international bodies, the scientific efforts are generally funded by individual nations, each with different priorities. The United Nations (UN) structure tends to be the primary forum for much of this coordination. However, an additional international, nonpolitical and non-governmental scientific perspective is afforded by the International Council of Science Unions.

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2. BACKGROUND

2.1 Trends in Water Issues Affecting Water Research Priorities

An increasing global population, coupled with a widespread desire for improved living standards, leads to increased demands for water of high quality. Consequently, the world is faced with increasing limitations to the availability of water for development and even for the maintenance of ongoing social and economic activities. The limitations on economic development caused by the lack of access to adequate useable water supplies in many developing countries are well known [See for example, *Boehmer et al.,* 2001]. In many developed countries, economic growth has proceeded rapidly over the last century, facilitated by a regional abundance of fresh water. However, serious constraints to growth are occurring, due to inadequate water supplies, even in some basins in these developed countries, particularly because of the rapid growth of urban centers and industrial activities and failure to account for year-to-year or even decade-to-decade variability in water availability arising from global climate variability. Nations without sufficient water resources are becoming aware that they may be able to overcome this limitation to their development only if they obtain increased access to water from other areas. There is a growing awareness that access to water can be secured through negotiated transboundary agreements or through a free market system if water is treated as a commodity. Science also has a critical role to play as needs for water increase and paradigms for water management shift. As *Rodda* [2001] eloquently states, "at a time when the demand for water is rising faster than at any previous moment in human history and more death and destruction are being caused by floods and droughts, it is vital that the scientific basis for action to alleviate these problems is strong and well founded."

2.2 Trends in Scientific Research

Over the past few decades, a view of hydrologic systems as a global concern, rather than just a mosaic of local or regional problems, has emerged. Following World War II, the development of international networks for the observation of global weather conditions led to an integrated perspective of climate systems and, in turn, encouraged the monitoring of water and energy cycle variables over the world's land areas. Since the 1960s, these capabilities have advanced in parallel with the development of increasingly sophisticated satellite systems for measuring these variables over land and ocean. In addition, the advent of advanced computing systems has accelerated the development of data assimilation and prediction capabilities.

Satellites, in particular, have changed our view of the water cycle. The ability to look at the Earth from space has given us a more holistic appreciation of the interactions between the elements of the Earth system. In a sense, Earth System science has developed as a new discipline that comprises an integrated understanding of the functioning of the various elements of the Earth system. For example, the role of water in the Earth system can be considered as an integrated unit. Although, historically, local and even national needs have dominated the requirements for hydrologic information, the science community is developing the theoretical framework needed for a dynamic global understanding of the water-cycle through the implementation of national and international water cycle research initiatives.

3. INTERNATIONAL POLICY ISSUES AND FRAMEWORKS

A number of issues are addressed in international discussions and activities pertaining to water resources and the contributions of the international hydrologic sciences. First, to what extent are current water resources of appropriate quality to satisfy the near-term social and economic concerns of the countries of the world? Second, are the relative quantities of available fresh water reserves changing, either because of short-term social conditions (e.g. uncontrolled increasing consumptive demand or removal from use by contamination) or long-term physical limitations (e.g. climate change with water balance impact)? Third, what technical or scientific capabilities, information and data are needed to address questions concerning adequate supplies? Fourth, how does the interaction between policy and the mechanisms of governance make use of scientific information to reach decisions regarding the management of resources on all timescales. Often this dialogue is hampered by a lack of understanding of the kind of information that scientists can provide to policy makers and of the types of information that are needed by policy makers.

Historically, societies have tended to treat water as a free public good to which everyone had a right to access. However, even early civilizations such as the Romans or Incas had water works projects, thereby introducing social controls (i.e. engineering works) into water-supply management and distribution. Facilitated by national policies and institutions, engineering capabilities during the last century rapidly increased the amount of water that was subject to control. [See, for example, *L'vovich*, 1979; *Beaumont*, 1979; *Linsley et al.*, 1982). More recently, environmental and community concerns have re-examined the reliance on storage development, and have led to a new emphasis on better information and more timely decisions as more effective ways to manage water. Accordingly, numerous international agencies now recognize the need to understand water use in a more socially and ecologically integrated way and to use that knowledge in the development of coordinated management programs.

Examples abound of the enlightened use of information to manage environmental problems within international frameworks. For example, successful efforts to curb ozone levels and, more recently, to develop a comprehensive understanding of the effect of the emissions of greenhouse gases to the atmosphere, provide some guidance on how society could address water issues. To deal with cross-boundary and international water management needs and their implications for regional economies, the global environment and world peace, it is essential to coordinate relevant issues and necessary supporting research in an international framework. The United Nations system provides a framework to develop initiatives for many of these coordinated efforts. The policy aspects of water issues are addressed in the United Nations Educational Scientific Cultural Organization (UNESCO) framework as well as through other UN initiatives. Many aspects of water hazards are addressed through the United Nations Environmental Programme (UNEP). In some cases, two international bodies coordinate the responses to a specific problem. For example, the Intergovernmental Panel on Climate Change (IPCC) is a coordinated effort between the World Meteorological Organization (WMO) and UNEP to undertake periodic assessments of the scientific, technical and socioeconomic information relevant for understanding the risks, including risks to water supply systems, arising from human-induced climate change.

The effective use of information about water resources is commonly constrained by factors such as legal agreements and requirements, conflicting issues affecting the management of the resource, and values attached by different communities to long-term environmental conditions and water security. In the case of tactical year-to-year decisions, information is often very critical during some seasons but of less value during other seasons because of the nature of the water management decisions that must be made. In order to understand the use of information in policy and management decisions, studies are needed of the role of institutional and policy factors in decision-making related to water resources. The International Human Dimensions Program (IHDP) seeks to understand the institutional and human factors that affect society's response to changes in water availability.

Water use is highly dependent on water quality, which, in turn, is closely tied to land use and land-use changes. Consequently, an effective water policy will need to include a land-use policy. For example, the drainage of wetlands and the gradual conversion of grasslands to managed agriculture have significant implications for the seasonal nature and magnitude of evaporation into the atmosphere. In addition, it can affect the quality of water percolation through the soils in areas where fertilizer is used extensively. These issues can be addressed only by a program whose primary focus is water.

The World Water Council (WWC), the UNESCO World Water Assessment Program (WWAP), and the Global Water Partnership (GWP) are all attempting to draw international and national groups together for dialogues that will facilitate the structuring of policy perspectives and the identification of issues that may transcend national boundaries. Some of these issues are short-term, such as flood warning systems requiring inputs and tactical water management decisions. Other considerations are long-term and depend on several evolving factors, including the increasing depletion of groundwater reserves, the increasing dependence of water systems on surface water of diminishing quality, multinational resource allocation issues, and the options for communities to deal with natural limitations (such as droughts) or social limits (such as those imposed by the development of certain types of industry). Long-term consequences can result from the cumulative effects of poor short-term water management decisions, and from the degree to which societies allow themselves to become more vulnerable to risks such as floods or water-borne diseases, as well as uncertain, but potentially important effects of climate change.

In order to address the complex issue of water planning at large scales, a number of socio-economic strategies need to be considered:

- more effective and integrated supply-side management;
- demand-side management, in accordance with a social evaluation of competing uses, including environmental protection;
- the development of regional and international markets among competing users;
- recycling of used water;
- the engineering of new technologies to increase local or regional supplies such as harvesting of cloud and fog water, desalinization, etc.
- conjunctive planning and use of surface and groundwaters.

The optimum mix of these strategies will depend on the regional and local patterns of supply and demand. Choices will be influenced by the values held by the national and regional governments overseeing the decision process. Both the assessment of the options and the enhancement of the efficiency of water use require inputs from the water science community to understand the vulnerabilities of sources and fluxes. Techniques are needed to allow for comparisons that show the advantage of one strategy over another. The next section reviews the progress of the hydrologic sciences as they have moved from addressing basin-scale issues to global-scale issues.

4. INTERNATIONAL HYDROLOGIC SCIENCES AND PROGRESSION FROM BASIN TO GLOBAL SCALES

Research pertaining to the hydrologic cycle typically examines either: (1) the physical processes governing the hydrologic cycle; or (2) the assessment and management of water resources, including hydrologic applications. This distinction is helpful in understanding the internationalization of research and development related to the hydrologic cycle as well as water resources management. Internationalization of research related to water resources management and hydrologic applications has achieved only limited success. The primary reason for this slower development is that many of the water resources problems of acute interest to society are experienced primarily at local, regional, and/or national scales. Depending upon the nature of problems in water resources (hazard mitigation, water supply, etc.), the issues often are viewed as sensitive and central to sociopolitical and legal disputes. For example, rivers that flow through two or more countries are sometimes at the center of disputes and controversy.

For reasons of sensitivity described above, the hydrologic information required for a thorough analysis at a basin scale may not be easily attainable. In this case, a few programs, such as the Flow Regimes from International Experimental and Network Data (FRIEND) program of UNESCO have shown some degree of success. FRIEND has provided a forum in which to share the necessary tools (such as models and new instrumentation technologies) and knowledge (how to use them) required to obtain a more complete understanding of regional conditions. Accordingly, the specific hydrologic application becomes the responsibility of a given country, and this approach reduces the likelihood of reluctance on the part of some nations to participate in international activities.

The area of physical hydrologic research has progressed more rapidly where international collaboration has increased. There are three critical functions in physical hydrology research: *observations*, *process studies,* and *system modeling*. Relatively speaking, a strong degree of collaboration and sharing of information at the international level occurs in the areas of process studies and modeling. The same cannot be said to date about the sharing of in situ measurements or other observations regarding specific water systems.

Historically, an understanding of the water cycle has been derived from observations at watershed or catchment scales; and the research was overseen by engineers. This research has been particularly important to individual communities and specific locales, because it pertains to preventing or mitigating damage from hydrologic hazards such as flooding and soil erosion, and ensuring adequate water supplies in times of drought. More recently, with the advent of satellite technology and the ability to observe large-scale hydrologic phenomena, hydrologic research has become internationalized, with the development of multinational hydrologic research programs interfacing with large-scale climate modeling projects. While satellite observations have been increasingly prolific, it has been a challenge to accumulate adequate corresponding ground-based measurements with which to calibrate these space-based data. In particular, many countries have very sparse, if any, hydrometeorological measurements, and other countries cannot or will not release their data because of national policy restrictions. This is a significant barrier to the international science community in many areas, including climate modelers [e.g. *International Association of Hydrological Sciences'* Ad hoc *Group on Global Water Data Sets*, 2001].

Various international activities, such as the Global Observing Systems, are addressing the information needs of both scientists and policy makers. A critical goal of international science is to construct a global data set of hydrometeorological information combining continental-scale and regional-scale process studies with improved and more expansive observational data sets available from satellites and in situ networks. The development and coordination of such a data set is one of the goals of the World Climate Research Programme's Global Energy and Water Cycle Experiment (WCRP-GEWEX) as well as several other programs discussed below.

In order to gain a better understanding of the global hydrologic cycle, comprehensive continental-scale and even regional-scale process studies are needed. If properly coordinated and planned, process studies can potentially provide readily transferable observational data in a standardized format, and can also improve hydrologic understanding of those aspects of the hydrologic cycle that contribute to a global perspective. In particular, hydrologists can discern how different aspects of the hydrologic cycle influence the accuracy and precision of land-surface/atmosphere models. Examples of successful process studies include: the First ISLSCP Field Experiment (FIFE; ISLSCP is the International Satellite Land Surface Climatology Project); Monsoon 90 Multidisciplinary Experiment; the Hydrology-Atmosphere Pilot Experiment in the Sahel (HAPEX-SAHEL); and the Semi-Arid Land-Surface-Atmosphere program (SALSA).

WCRP focuses on the development of climate prediction techniques that will allow prediction on seasonal to century-long timescales, and GEWEX deals with global and regional data set development to support climate model development and climate process research, as well as the use of these data in improving our understanding of the global water cycle. In particular, GEWEX coordinates a number of global data set development activities, including ISLSCP, the Global Precipitation Climatology Product, and the Global Runoff Data Center, to name a few. Through its Global Hydrometeorology Panel (GHP) and the Continental Scale Experiments (CSEs), GEWEX was the first to internationally coordinate the establishment of nine continental-scale or regional-scale river basins on five continents through six Continental-scale Experiments (see http://www.gewex.com/cseslocation.html). Over the past decade, scientists involved with the GEWEX program have contributed to intensive studies of specific hydrological regions through these CSEs. These continental-scale studies provide improved observations and coupled land-atmosphere models for data assimilation and prediction purposes. Some of these experiments, such as the GEWEX Continental-scale International Project (GCIP), have reached maturity and are being followed by extensions such as the GEWEX Americas Prediction Project (GAPP), which focuses on seasonal timescales.

International research programs support applications efforts such as UNESCO's International Hydrologic Program (IHP) and its two primary study programs, FRIEND (described above) and the Hydrology for Environment, Life and Policy (HELP) initiative. The IHP's purpose is to improve the scientific and technological basis for the development of methods and expertise for rational management of water resources including environmental protection, and to integrate developing countries into worldwide ventures of research and training. UNESCO is placing a growing emphasis on the use of knowledge and forecasts by local communities. FRIEND is primarily an international research program whose goal is to develop an understanding of the hydrologic variability among regions of the world. This is accomplished in a cooperative manner through mutual exchange of data, techniques and knowledge among FRIEND scientific partners. In contrast, HELP focuses in depth on individual regions seeking to characterize both environmental and anthropogenic/policy concerns. HELP has identified more than 25 basins for study. These basins cover a range of socioeconomic and climatic conditions. In general, the scientific developments from this research find their way into operational services through the national agencies responsible for flood prediction and resource management. A number of countries have hydrologic services that provide users with forecasts for river levels and volumetric flows.

UNESCO has also recently accepted the Dutch Government's offer to transform IHE-Delft (International Institute for Infrastructure, Hydraulic and Environmental Engineering in Delft) into the UNESCO-IHE Institute for Water Education to make the most recent knowledge on water management accessible to water managers throughout the world [*UNESCO*, 2001]. Through the efforts of the World Meteorological Organization's (WMO's) Hydrology program, new technologies are made known to these national hydrometeorological operational agencies. WMO programs that facilitate the transfer of models, technologies and data among nations also make an important contribution to these efforts.

Ultimately, many of these international research programs, which receive significant support from space agencies, contribute to improvements in the ability of satellites to provide more accurate hydrologic information at relevant spatial and temporal scales. This will be helpful in bridging the gap between the definition of hydrologic fields at global scales and what can be provided by the regionally limited and sometimes hard-to-obtain hydrologic data systems. Scientists will then be able to continue the work toward understanding processes and developing improved prediction models for the benefit of water resources management.

The International Council of Scientific Unions (ICSU) also fosters international research pertaining to hydrology on a global scale, both through the activities of its 25 scientific member unions and through special committees. Directly relevant to the promotion of hydrologic sciences is the ICSU member International Union of Geodesy and Geophysics (IUGG) and its semi-independent member association, the International Association of Hydrologic Sciences (IAHS) that serves as a communications forum for a number of international process studies. Various ICSU special committees also have objectives touching on water resource issues. The Scientific Committee on Problems of the Environment (SCOPE) fosters international research pertaining to hydrology on a global scale, albeit indirectly, through its focus on global environmental and ecological issues. It includes a number of projects with hydrologic components because of the importance of water to the functioning of ecosystems. For example, the SCOPE project, "Nitrogen Transport and Transformations" [see http://www.nceas.ucsb.edu/public/scope-n/wgl.html] has multiple objectives, including the development of a regional and ultimately a global understanding of nutrient export to coastal areas. Indeed, the globalization of hydrologic research has come about not only because of the need to encourage more nations to share hydrologic data to improve models, but also because many nations share regional ecological challenges and all nations may be affected by the global-scale consequences of anthropogenic alteration of the Earth's ecosystems. One of the major environmental issues forcing hydrologists to develop a global perspective is climate change and its implications for water resources in every part of the globe.

5. GLOBAL CLIMATE ISSUES: DEVELOPING HYDROLOGY TO ADDRESS GLOBAL EARTH SYSTEM SCIENCE NEEDS

The uncertainties surrounding climate change and climate variability issues cannot be understood without a systematic understanding of the global water cycle. For example, processes whereby water moves from the land and ocean through transpiration and evaporation, from the atmosphere to the land through precipitation, and from the land to the ocean by runoff and groundwater outflow need to be understood and quantified. A number of important water cycle issues have been raised in the context of climate change. Recently an IPCC report stated that the inability to model precipitation over as large an area as the Amazon basin "reflects our poor understanding of the interaction of convection and land surface processes" (IPCC, 2001). According to the US National Assessment report on the water sector, reliance on traditional management mechanisms may be untenable in view of the anticipated effects of climate change on water resources. [*Gleick* and *Adams*, 2000]. In addition, the consequences of potential changes in precipitation and temperature patterns for nations and communities are also important issues that are not likely to be adequately addressed in traditional water resources management strategies.

Due to the global nature of atmospheric processes, hydrology must be able to address the climate-hydrology interface at all scales up to global. Some water programs have adopted climate issues as a priority theme; accordingly, they give emphasis to the consequences of changes and variations in temperature and precipitation patterns. Furthermore, changing patterns of use must be monitored to ensure that changes in climate do not threaten the ability of the supply systems to meet their existing commitments.

An important, relatively new component of the WCRP, initiated by GEWEX, is the Coordinated Enhanced Observing Period (CEOP). As discussed in a later paragraph, the Committee on Earth Observing Satellites (CEOS) is also a partner in this initiative. CEOP is a cooperative effort being carried out in the 2001-2004-time period to compile global-scale continental data sets derived from a new generation of satellites. By collecting data on different continents, all of which represent different hydrologic ecosystems, modelers aim to test the transferability of data estimates to other, unsampled but hydrologically similar locations. The ultimate goal is to improve the predictability of the climate affecting water resources planning and management in various regions of the world.

Another program that studies hydrologic and land surface processes pertaining to but extending beyond climate-related concerns is the Biospheric Aspects of the Hydrologic Cycle (BAHC) program within the International Geosphere-Biosphere Program (IGBP). Studies conducted through this initiative provide a basis for studying the effects of land use changes on runoff, and assessing the consequences of climate change for water resources by downscaling climate model scenarios to assess the consequences for water resources in a particular basin.

The involvement of the hydrologic sciences in climate issues has introduced new requirements for, and approaches to, global observations. Global and regional data sets are needed for the development of global and regional hydrological models that are needed, in turn, to support climate studies. Furthermore, macro-scale policies and management rely on continued access to data and data products to provide baseline information on resource inventories and the factors that may influence future resource availability. Some data programs are maintained for reasons in addition to climate because they provide a basis for assessing effects of land use, urbanizations, etc. In order to address data issues, many international organizations have programs that are focused on water-related issues (see Appendix A). Some of these programs promote work that addresses the social dimension of water resources (e.g. FAO, UNESCO, IHDP, HELP); others directly pertain to anticipating questions of change (e.g. UNFCC). Still others are directed toward developing scientific capabilities pertaining to these water-related questions (WCP, WCRP, and GEWEX), while some promote the sharing of data and technology transfer on a global basis for climate and other purposes (GTN-H, GCOS, GTOS, GOOS, GEMS, GPCC, GRDC, WHYCOS, FRIEND).

Three interconnected international activities, known as the *Global Observing Systems,* were established in the 1990s specifically to address the needs of both scientists and policy makers to understand the Earth system as a whole and to provide a capability to monitor changes in the Earth's climate. These three systems are the Global Climate Observing System (GCOS), Global Terrestrial Observing System (GTOS) and Global Ocean Observing System (GOOS). The purpose of GCOS is to ensure that the comprehensive, long-term observations and information (atmospheric, oceanic, terrestrial and cryospheric) needed to improve our capability to detect, predict and assess climate change, are obtained and made available to all potential users. Like many international activities, GCOS does not itself directly make observations nor generate data products; rather, it facilitates the coordination and collaboration of national and international observational programs. GTOS was established to provide necessary data to policy makers, resource managers, and researchers in order to detect, quantify, and give early warning of changes in the capacity of terrestrial ecosystems, with the ultimate goal of supporting sustainable development and improvements in human welfare. GCOS and GTOS share a joint scientific advisory panel called TOPC, Terrestrial Observation Panel for Climate, which has produced an analysis of information and actions needed to concurrently address GCOS's and GTOS's climate-related goals. The key variables discussed in this plan are listed in Appendix B.

The Integrated Global Observing Strategy (IGOS) is an important mechanism for coordinating global observational programs. In particular, the IGOS Partners, their working groups, and their Committee on Earth Observing Satellites (CEOS) were formed to provide more effective coordination between the international science and resource management organizations and the national agencies that implement observing systems. IGOS-Partners recently approved the development of a Global Water Cycle theme that will provide a framework for water-related observations. Coordination will be directed at three priorities that have been identified: precipitation, surface hydrology and water resource applications, including irrigation. The theme also provides an umbrella for the ambitious WCRP/CEOS CEOP initiative described earlier in this chapter.

6. APPLYING INTERNATIONAL HYDROLOGIC SCIENCE TO GLOBAL POLICY ISSUES

The major policy framework for addressing international water issues is provided by the UN. The UN approach is based upon the principles embodied in its charter, namely the promotion of peace and equality among the people of the world, and the protection of societies from threats that may lead to widespread loss. Access to natural resources, including water, is correlated with the economic activity of the country. The world-wide adoption of the principle of sustainable development as outlined in what is generally known as *"The Brundtland Report" [World Commission on Environment and Development*, 1987] is widely regarded as a feasible path for achieving a system of long-term global stability. In order to clarify its approach to water and other renewable resources, the UN has structured many of its new initiatives around the theme of sustainable development. Obstacles that prevent the achievement of these goals include different cultural practices, limited access to educational capabilities, differences in technologies between developed and developing countries, and the inability to predict medium and long-term variability of water supplies. The contributions of science are greatest when the research provides techniques and information that deal with these obstacles. International science programs that have an element devoted to capacity building and technology transfer, in addition to improving scientific understanding, are most effective in the international arena.

Water is a critical factor in the war on poverty. Water for human consumption is a primary social concern because clean water is critical for life and is important for health. Contaminated water accounts for more than 3 million deaths per year worldwide [*World Health Organization* (*WHO*)—see http://w3.whosea.org/wwd/waterdises.htm]. The provision of clean water is a problem particularly in poorer countries where the sanitation systems are commonly woefully inadequate. This is a primary concern of the Water, Sanitation and Health Program of WHO. Water is also important for food production, notably livestock support and agricultural production, especially in areas where rain is inadequate to support crops without the use of irrigation. Water is also needed for industrial productivity and the production of energy. The Global Environment Monitoring System Freshwater Quality Programme (GEMS/Water), sponsored by UNEP, is an international science programme that focuses on providing information for freshwater quality issues throughout the world. It seeks an understanding of these issues through sharing monitoring and assessment information for both surface and groundwaters, and fosters capacity building in sixty-nine countries around the world.

International science supports these global objectives in a number of ways and is partitioned into programs that focus on one or more of these priority areas. In general, the goals of these programs also reflect the interests of the scientists who developed them and the agencies that fund them, leading to a rather open-ended mosaic of programs rather than a monolithic coherent structure. From a management perspective, however, it is important that the overarching policy questions be addressed through a combination of research, development and public education. It is critical that scientific programs such as UNESCO/IHP and WCRP inform exercises such as the World Water Forum to ensure that they provide substantive and reliable input to the broader sustainable development agenda. A number of case studies to demonstrate the importance of information sharing and transfer are also underway through the World Water Assessment Program (WWAP) and other studies within the CSEs are being coordinated by the GEWEX Water Resources Applications Project (WRAP). Another important coordination mechanism for the hydrological sciences is the International Association of Hydrological Sciences (IAHS), which has established a number of working groups to enable it to influence both the governmental science programs as well as the policy issues involving water quantity and quality.

Specific scientific programs have been developed to examine the global policy issues and to explore the potential links between the physical sciences and the policy agenda. The International Human Dimensions Programme (IHDP) on Environmental Change also places an emphasis on studies of human interactions with the fresh water cycle. In particular, IHDP seeks to achieve water and environmental security through a well-integrated socio-hydroecological approach to water problems. This programme supports a number of projects aimed at understanding how human interactions with the global water cycle can be addressed through integrated catchment management or superstructures (e.g. legislation, financing) to allow for certain actions to be taken. IHDP interests in security issues, vulnerability and global environmental change, and sustainability science all create opportunities for researching the links between the user needs and the abilities of science to support this development. While the physical sciences address problems such as the lack of the resource, the Human Dimension program is needed to assess water scarcities that are the result of political and social challenges to manage the resource.

In order to develop a more integrated approach to problems related to environmental science and global water issues, a Global Water System Project (GWSP) involving WCRP, IGBP, IHDP and Diversitas has been established. The GWSP addresses two major questions: "how are humans changing the global water cycle, the associated biogeochemical cycles, and the biological components of the global water system, and what are the social feedbacks arising from these changes?" [*Hoff*, 2002]. The science questions underpinning this project relate to inventorying changes in the global water system, determining mechanisms whereby human activities affect the global water system and determining the degree to which the global water system is resilient to global change. The challenges posed by these questions are addressed through a number of the activities of the Global Environmental Programmes, most notably WCRP and IGBP.

The Global Water Partnership (GWP) is an important policy framework that was formed in 1996 to promote and implement integrated water resources management through the development of world-wide networks of partnerships that could coordinate financial, technical, policy, and human resources to address the critical issues related to sustainable water management, such as domestic water services for the poor and maintaining water for ecosystems [*van den Heuvel* and *Willemse*, 2001]. Although it is not feasible to consider a world-wide water management policy, water must become an important element of major global environmental programs. Partnerships like the GWP rely on influencing the development of global approaches by contributing to awareness activities within programs such as the World Summit on Sustainable Development. The GWP has established a number of technical committees covering all continents except North America. It uses cross-sector dialogue on common water problems and develops action plans based on integrated water-resources management to resolve these problems. In part, this is done through the promotion of an Integrated Water Resource Management (IWRM) package that facilitates the coordinated development and management of water, land and related resources. Technology-oriented projects must draw upon the scientific capabilities of participating nations in the relevant international programs.

7. MECHANISMS AND CHALLENGES IN THE COORDINATION OF INTERNATIONAL SCIENCE

7.1 Mechanisms

Science efforts at the international level have tended to involve large projects that entrain a number of scientists from different regions. Because of their inherently large size and the opportunities they provide for international collaboration, these projects often attract some of the best and most visionary researchers from each nation. International project leaders tend to be facilitators who draw together international scientists to develop science plans, coordinate implementation and discuss research results. In many cases, the activities funded by individual nations are coordinated through UN special agencies, such as WMO and WCRP that establish project offices for specific initiatives. These offices oversee the development of science plans that are subsequently funded by various nations. Individual nations are encouraged to come forward with their contributions to these international efforts and to outline how they plan to contribute. Commitment conferences have been found to be an effective means for securing investments from various countries for specific programs. Generally, the largest contributions for water programs come from the United States, Europe, and Japan. There appears to be a second tier of funders, including Brazil, China, Canada and Australia, with other countries contributing as they can. The three major funders all maintain strong space programs and consider global water cycle issues as part of their observations and research related to the Earth system, although Europe and Japan provide more support for international programs dealing with water demand issues (such as UNESCO, WWAP).

International research programs, such as WCRP and its components, have progressed by coordinating, influencing and guiding national research activities to achieve the goals set out in their respective international science plans. This approach has been successful where strong leadership is provided at the international level. Frequently, this scientific leadership is provided through a scientific committee and a project office or a secretariat to coordinate the actions. In addition, nations or agencies make specific commitments to carry out certain aspects of the research program and these international offices must track their progress and ensure that their work contributes to the projects carried out by other countries. One challenge for this approach arises from the lack of suitable scientific experts who are willing to fill coordination roles at both national and international levels.

National and international programs tend to be implemented in an iterative and symbiotic way. International programs are commonly developed in coordination with national programs that provide the initial intellectual framework and, within limits, funding. National programs provide critical support for international programs, while international programs place national programs in a broader context that allows for these programs to achieve more comprehensive objectives and aid in developing a broader base of support within their own countries. National programs are generally stronger when they consider global objectives and linkages in their formulation.

In many international environmental programs, targets are frequently established at the international level, and nations and programs are asked to commit to helping achieve those targets. Earth Summit Agenda 21, crafted in Rio in 1992, represented one such overarching agreement for advancing the sustainable development agenda on a broad scale. National commitments to these goals are uneven, however, as periodic reviews of progress toward this agenda indicates. In the section of the Agenda 21 report [*UN*, 1993] dealing with the protection of the quality and supply of fresh water resources, priority activities are identified for: 1) integrated water resources development and management; 2) water resource assessment; 3) protection of water resources, water quality and aquatic ecosystems; 4) drinking water supply and sanitation; 5) water and sustainable urban development; 6) water and sustainable food production and rural development; and 7) impacts of climate change on water resources. In an ideal world, international research programs would address these issues in setting their priorities.

7.2 Challenges

Progress in understanding the global water cycle requires observations, process studies and modeling studies. As is evident in this paper, there are a number of international programs that address process and modeling studies, where needs exist for improved coordination. In addition, through the efforts of the space agencies and related international activities, the availability and use of satellite data are growing. However, in view of the need to validate these satellite data, the single most pressing international science issue involves the diminishing availability of in situ information due to the erosion of traditional observing networks, the loss of historical data sets because of a lack of adequate quality control and archiving policies, and the lack of incentive for nations to share data across international boundaries. In many countries, routine hydrological observations are made that could be used for climate research and monitoring purposes and for freshwater assessments. However, there is no international hydrological network that operates on a standardized set of procedures for data collection, dissemination, analysis and use. Even many international hydrological research programs, such as FRIEND, limit mutual exchange of data to the community of their scientific partners.

Many factors are contributing to the shrinkage of hydrologic information globally, both as a result of the physical erosion of monitoring systems and the tendency of countries to be less willing to share global data [*International Association of Hydrological Sciences'* Ad hoc *Group on Global Water Data Sets*, 2001].

Nonetheless, this is also a particularly optimistic time for the data exchange issue in the light of WMO Resolution 25 (CgXIII) on the free and unrestricted exchange of hydrological data and products adopted by the Thirteenth WMO Congress in June 1999. In the summer of 2000, a panel of experts met to discuss the establishment of a global hydrological observation network for climate. [*Cihlar et al.*, 2001]. This report recommends a mechanism or network for sharing hydrologic information that would meet policy and science requirements in the area of climate research and management goals. This network, known as the Global Terrestrial Network for Hydrology (GTN-H), would satisfy many requirements for information beyond those arising from climate questions. The GTN-H has recently been adopted as an active international project under the sponsorship of GTOS, GCOS and WMO/HWRP.

8. RECOMMENDATIONS FOR A WAY FORWARD

Over the last two decades there has been a growing awareness of the need to link the distribution of water to globally teleconnected patterns. Today, a substantial international effort is directed at developing an understanding of the global dynamics of hydrologic systems and their physical and societal links to water resource issues. Considerable progress has occurred in the last two decades toward developing science programs that help solidify our understanding of continental-scale water cycle processes and their links to climate processes, as well as the mechanisms that transfer energy and materials from the land to the ocean. However, the approach to global water problems is not seamless, as weaknesses exist in the scientific efforts on some topics and in some regions. More basin-scale science programs are needed to test the knowledge from smaller- scale studies in order to address global change issues and to resolve the world's large-scale water issues. In addition, there are obstacles and impediments to conducting international water research in support of global policy issues. Possible ways to strengthen international hydrologic endeavors are suggested below.

Currently, a dominant theme in earth resources studies is the quantification of global change at all scales in the Earth system. In addition, assessments of the consequences of climate change for water resources have encouraged global views of changing patterns of water availability. Studies promoted by the IPCC and the UNFCC have contributed to a consensus on the importance of climate change as an issue for international attention. Perhaps even more importantly, these studies have drawn attention to the need to more fully address the potential impact of climate change on water resources. However, even apart from any consideration of climate change, a strong argument can be made for establishing an independent program to facilitate research and the sharing of information about water systems within a global context, both for social and scientific reasons. While the distribution of water resources could be affected by climate change, other critical factors are known to influence the quantity and quality of water, and thus affect the total resources available. A focused effort should be directed at developing the intergovernmental cooperation needed to achieve Agenda 21 objectives for water.

The erosion of national hydrometric observational networks is a trend that is disruptive to developing a comprehensive understanding of the water cycle. The resulting gaps in these networks can only partially be filled by remote sensing data. Furthermore, in situ measurements are needed for the calibration and validation of remotely sensed data as well. An overall strategy for hydrometric measurements over land must be developed, and nations should be encouraged to make commitments to support it. The free and open access to hydrometric data should be adopted as a basic principle for this network. WMO Resolution #25, which provides a basis for more liberal national data exchange policies, should be applied to these networks.

Since World War II, the United States and other developed countries have tended to be strong players in international programs in which there is a major atmospheric component. Despite recent precautionary restrictions on public domain hydrologic knowledge as a result of post-September 11, 2002 security considerations, the USA has been and continues to be a leader in making its hydrologic information available to all users [see http://www.water.usgs.gov] at a time when even some developed countries will make their data available only for a cost, if at all. However, the lack of US involvement in some of the mainstream application programs such as UNESCO has led to a reduction of US international contributions in these areas. Despite this disconnect, the USA has some excellent applications programs at the regional and national levels (e.g. NOAA's Regional Integrated Science and Assessment projects). In addition, satellite agencies, especially NASA, have contributed to a global perspective of surface water distribution. The challenge is to forge a unified approach for the study of global hydrologic systems. A broader and more open US approach to water issues discussed in certain fora, such as UNESCO, could strengthen national programs and ensure that the views of the United States are effectively introduced to the full international community.

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APPENDIX A: TABLE OF INTERNATIONAL ACTIVITIES CONCERNED WITH WATER RESOURCES

I. ICSU Based

ICSU - International Council for Scientific Unions
http://www.icsu.org/
IGBP- International Geosphere-Biosphere Programm
http://www.igbp.kva.se
(ICSU)

BAHC - Biospheric Aspects of the Hydrological Cycle
http://www.PIK-Potsdam.DE/~bahc/
(IGBP)

IUGG - International Union of Geodosy and Geophysics
http://www.iugg.org/eoverview.html
(ICSU)

IAHS - International Association of Hydrologic Sciences
http://www.cig.ensmp.fr/~iahs/index.html
(IUGG)

IHDP - International Human Dimensions Program
http://www.uni-bonn.de/ihdp
(IGBP, WCRP & DIVERSITAS)

II. UN Based

UN - United Nations
http:// www.un.org and http://www.unsystem.org

FAO - Food and Agriculture Organization
http://www.fao.org
(UN)

IAEA - International Atomic Energy Association
http://www.iaea.org/
(UN)

GNIP and ISOHYS - Global Network for Isotopes in Precipitation and Isotope Hydrology Information System
http://isohis.iaea.org
(IAEA & WMO)

UNEP - United Nations Environment Programme
http://www.unep.org
(UN)

GEMS-Water - Global Environment Monitoring System - Water
http://www.cciw.ca/gems/
(UNEP)

IPCC - Intergovernmental Panel on Climate Change
http://www.ipcc.ch
(UNEP & WMO)

UNESCO - United Nations Environment, Science, and Cultural Organization
http://www.unesco.org/
(UN)

IHP - International Hydrologic Programme
http://www.unesco.org/water/ihp/index.shtml
(UNESCO)

FRIEND - Flow Regimes from International and Experimental
Network Data
http://www.nwl.ac.uk/ih/www/research/bfriend.html
(IHP)

HELP - Hydrology for Environment, Life and Policy
http://www.nwl.ac.uk/ih/help/index.html
(IHP)

IWE - Institute for Water Education
http;//www.ihe.nl/vmp/articles/News/NEW-Unesco-
GC_decisions.html
(UNESCO & IHE Delft)

IOC - Intergovernmental Oceanographic Commission
http://ioc.unesco.org/iocweb
(UNESCO)

WWAP - World Water Assessment Program
http://www.unesco.org/water/wwap/index.shtml
(UNESCO)

UNFCCC - United Nations Framework Convention on Climate Change

http://www.unfccc.de
(UN)

WHO
World Health Organization
http://www.who.int/home-page
(UN)

WSH - Water, Sanitation and Health
http://www.who.int/water_sanitation_health/index.html
(WHO)

WMO
World Meteorological Organization
http://www.wmo.ch/
(UN)

HWRP - Hydrology and Water Resources Programme
http://www.wmo.ch/web/homs/hwrphome.html
(WMO)

WHYCOS - World Hydrologic Cycle Observing Systems
http://www.wmo.ch/web/homs/whycos.html
(HWRP)

III. Organizations Sponsored by ICSU and UN

GCOS - Global Climate Observing System
http://www.wmo.ch/web/gcos/gcoshome.html
(ICSU, IOC, UNEP, WMO)

GTOS - Global Terrestrial Observing System
http://www.fao.org/GTOS
(ICSU, FAO, UNEP, UNESCO & WMO)

TOPC - Terrestrial Observation Panel for Climate
http://www.wmo.ch/web/gcos/topc.htm
(GCOS, GTOS)

GOOS
Global Oceanographic Observing System
http://ioc.unesco.org/goos
(ICSU, IOC, UNEP, WMO)

GOSIC - Global Observing Systems Information Center
http://www.gos.udel.edu
(GCOS, GTOS, GOOS)

WCP - World Climate Programme
http://www.wmo.ch/web/wcp/wcp_prog.htm
(ICSU, IOC, UNEP & WMO)

WCRP - World Climate Research Programme
http://www.wmo.ch/web/wcrp/wcrp/home.html
(WCP)

GEWEX - Global Energy and Water Cycle Experiment
http://www.gewex.com
(WCRP)

GHP - GEWEX Hydrometeorolgy Panel
http://www.usask.ca/geography/MAGS/GHP/ghp.html
(GEWEX)

GPCC - Global Precipitation Climatology Center
http://www.dwd.de/research/gpcc
(WCRP)

GRDC - Global Runoff Data Center
http://www.bafg.de/grdc.htm
(WCRP)

ISLSCP - International Satellite Land Surface
Climatology Project
http://www.gewex.com/islscp.html
(GEWEX)

FIFE - First ISLSCP Field Experiment
http://www-eodis.ornl.gov/daacpages/fife.html
(ISLSCP)

HAPEX-SAHEL-Hydrology - Atmosphere Pilot
Experiment in the Sahel
http://www.orstom.fr/hapex/index.html
(GEWEX, CESBIO, ORSTOM, CNES)
CEOP - Coordinated Enhanced Observing Period
http://www.usask.ca/geography/MAGS/GHP/ceop.issues.html

(WCRP, IGOS, CEOS)

IV. OTHER
IGOS-P - Integrated Global Observing Strategy – Partners
http://ioc.unesco.org/igospartners/igoshome.htm
(UNESCO, IOC, WMO, WCRP, IHDP, IGBP, FAO, CEOS, GOOS, GCOS, GTOS)

WWC - World Water Council
http://www.worldwatercouncil.org
(UNDP, UNESCO, World Bank, CIDA, CIHEAM, ICID, IUCN, IWA, IWRA & WSSCC)

WWF - World Water Forum
http://worldwaterforum.net
(World Water Council)

GWP
Global Water Partnership
http://www.gwpforum.org/
(Membership Organizations)

11. APPENDIX B

Nine key hydrospheric, cryospheric and biospheric variables for the assessment of climate impacts on water resources were identified in the GCOS/GTOS Plan (1997), namely:
surface water flow - discharge;
surface water storage fluxes;
ground water storage fluxes;
precipitation;
evapotranspiration,
relative humidity;
snow water equivalent;
soil moisture; and
biogeochemical transport from land to oceans.

A tenth variable, water use, was added by the Terrestrial Observation Panel for Climate (1999) because this flux is needed not only for sociological and economic studies of water resources, but also to assess the dynamics of the terrestrial water cycle of which anthropogenic impacts are now understood to be a key component. A perusal of these variables will clearly indicate that they provide information that is useful for far more than just climate related issues.

12. APPENDIX C: ACRONYMS

BAHC – Biospheric Aspects of the Hydrologic Cycle
CEOP – Coordinated Enhanced Observing Period
CEOS - Committee on Earth Observing Satellites
CSE - Continental Scale Experiment
FAO – Food and Agriculture Organization
FRIEND – Flow Regimes from International and Experimental Network Data
GCOS – Global Climate Observing System
GEMS – Global Environmental Monitoring System
GEWEX- Global Energy and Water Cycle Experiment
GHP – GEWEX Hydrometeorology Panel
GOOS – Global Oceanographic Observing System
GPCC – Global Precipitation Climatology Center
GTN-H – Global Terrestrial Network Hydrology
GRDC – Global Runoff Data Center
GTOS – Global Terrestrial Observing System
GWP - Global Water Partnership
GWSP – Global Water System Project
HELP – Hydrology for Environment, Life and Policy
HWRP - Hydrology and Water Resources Program
IAHS – International Association of Hydrologic Sciences
IGOS – Integrated Global Observing Strategy
IHDP – International Human Dimension Program
IHP – International Hydrology Program
IPCC – Intergovernmental Panel on Climate Change
IWRM – Integrated Water Resource Management
TOPC – Terrestrial Observation Panel for Climate
UN – United Nations
UNEP – United Nations Environmental Program
UNESCO – United Nations Environment, Science and Cultural Organization
UNFCC – United Nations Framework Convention on Climate Change
USGCRP – United States Global Change Research Program
WCP – World Climate Program
WCRP – World Climate Research Program
WHO – World Health Organization
WHYCOS – World Hydrology Cycle Observing System
WMO – World Meteorological Organization
WRAP – Water Resources Application Project
WWAP – World Water Assessment Program
WWC – World Water Council